GÓRNICTWO ODKRYWKOWE nr 6/2018

METODA DOBORU MIEJSC DO MONITOROWANIA STANU WYTĘŻENIA USTROJÓW NOŚNYCH PODWOZI MASZYN PODSTAWOWYCH GÓRNICTWA ODKRYWKOWEGO

SITES SELECTION METHOD FOR MONITORING THE EFFORT OF CHASSIS LOAD- BEARING STRUCTURES IN BASIC MACHINES FOR OPENCAST MINING

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Przedstawiono charakterystykę ustrojów nośnych podwozi maszyn podstawowych górnictwa odkrywkowego. Zaprezentowano identyfikację obciążeń ustrojów nośnych podwozi. Podano wykaz obciążeń mających największy wpływ na stan wytężenia konstrukcji podwozi. Przedstawiono metodę doboru miejsc monitorowania stanu wytężenia ustrojów nośnych podwozi maszyn podstawowych górnictwa odkrywkowego. Opisano szczegółowo jej kolejne etapy. Podano przykłady wykorzystania powyższej metody do badań stanu wytężenia ustrojów nośnych maszyn podstawowych pracujących w górnictwie odkrywkowym.

Słowa kluczowe: *maszyny podstawowe, ustroje nośne, podwozia, obciążenia, wytężenie, monitoring*

Characteristic of chassis load-bearing structures in basic machines for opencast mining has been presented in the paper. Identification of loads of chassis load-bearing structures has been showed. A list of loads having the greatest impact on the effort of the chassis structure has been given. Sites selection method for monitoring the effort of chassis load bearing structures in basic machines for opencast mining has been presented. Its sub-sequent stages have been described in details. Examples of the use of the above method for testing the effort of load-bearing structures in basic machines operating in opencast mines have been provided..

Keywords: *basic machines, load-bearing structures, chassis, loads, effort, monitoring*

Introduction

Crawler chassis in basic machines for opencast mining due to the need to carry very large loads (mainly due to their own weight), complicated construction and movement on unpaved and often non-dewatered grounds belong to the most strenuous assemblies of load-bearing structures. Hence, they are often subject to various failures, which in extreme cases can even lead to a disaster (complete destruction) of the machine [1]. In order to prevent these unfavourable phenomena, load-bearing structures of the basic machines chassis are subjected to various tests, which in the most cases, are the stress tests of the most strained components [2][3]

In contrast to the stresses of the superstructure components, for which the spectrum of loads is usually specified, the load of the chassis is very complex, resulting not only from their deadweight and mining forces, but also from the interaction with the non-linear ground and the characteristics of crawler travel mechanisms. Therefore, the issue of determining sites for stress testing is not a simple matter and has not been fully solved so far. In order to facilitate this task in the future, it was decided to develop sites selection method for monitoring the effort of chassis load- bearing structures in basic machines for opencast mining.

Characteristic of chassis load-bearing structures in basic machines for opencast mining

The function of the basic machines chassis is to transfer the weight of the machine and all external loads acting on it to the ground and to move the machine both during the working process and during its transport [4]. The chassis of these machines are required to:

- carry very heavy loads, because these machines belong to the heaviest self-propelled machines designed by man,
- move on grounds with unfavourable carrying properties, often without prior preparation and surface dehydration,
- overcome small hills; the range of allowable inclinations of the machine is limited due to the large overhangs of the working units.

Fig. 1. View of BWE crawler chassis [18]
Rys. 1. Widok podwozia gąsienicowego koparki wielonaczyniowej kołowej

For bucket-wheel excavators (BWEs) used in the national opencast mining of lignite – weighing up to 11,000 tonnes – crawler chassis are commonly used (Fig. 1). They are characterised by a large plate surface, meeting the requirement of small pressures on the ground. Relatively low travel speeds (up to 10 m/min) are sufficient to change the position of the machine during operation, and are large enough to allow their manoeuvrability.

The following features can be considered the advantages of crawler chassis [5]:

- relatively high manoeuvrability and the ability to move in any direction,
- small turning radiuses,
- significantly higher hill climbing capacity than previously used rail chassis and avoidance of significant costs associated with maintenance and sliding of tracks,
- the possibility of obtaining high tractive force.

On the other hand, the disadvantages of this type of chassis are as follows:

- significant failure frequency and wear of drive components, especially crawler chains,
- the traction resistance is significantly higher compared to the rail chassis and, therefore, increased power consumption.

The condition of even loading of the running assemblies requires the use of a statically determined load-bearing structure, which is obtained by three-point support of the entire structure (the so-called supporting triangle) (fig. 2), and the attachment of individual traction components through the appropriate lever-rockers.

Rigid chassis structures used in smaller machines or those operating in other conditions, such as harbour cranes, are completely unusable in opencast mines. Meeting the condition of a small unit load on the ground requires that for a given size of the excavator and its weight, there should be a sufficiently large supporting area of the chassis. This entails the extension of the chassis of the basic machines for opencast mining to dimensions not found in other machines, creating specific design and operational issues.

Identification of loads of chassis load-bearing structures

The basic machine chassis usually consists of an ring-shape girder mounted on the chassis portal, crawler girders that support the chassis portal and traction components including crawler chains with drive mechanisms, mounted on a crawler girder (Fig. 3).

Chassis portals of high-performance BWEs are assemblies with a relatively complicated structure [6]. The load-bearing structures of portals are usually spatial plate girders or beam structures (Fig. 1). Crawler girders are usually spatial plate girder structures of significant dimensions.

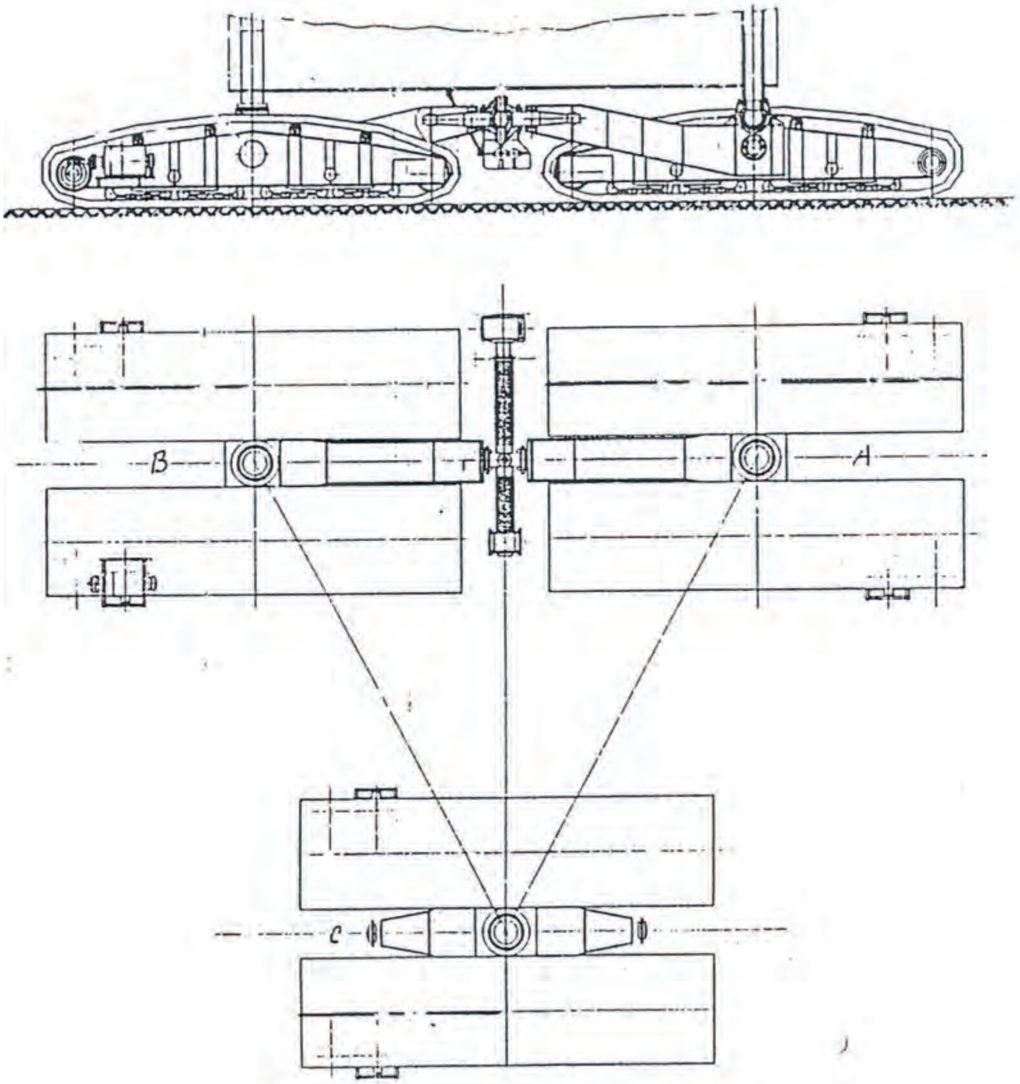

Fig. 2. BWE SchRs 4000 chassis assembly [18]
Rys. 2. Układ podwozia koparki SchRs 4000

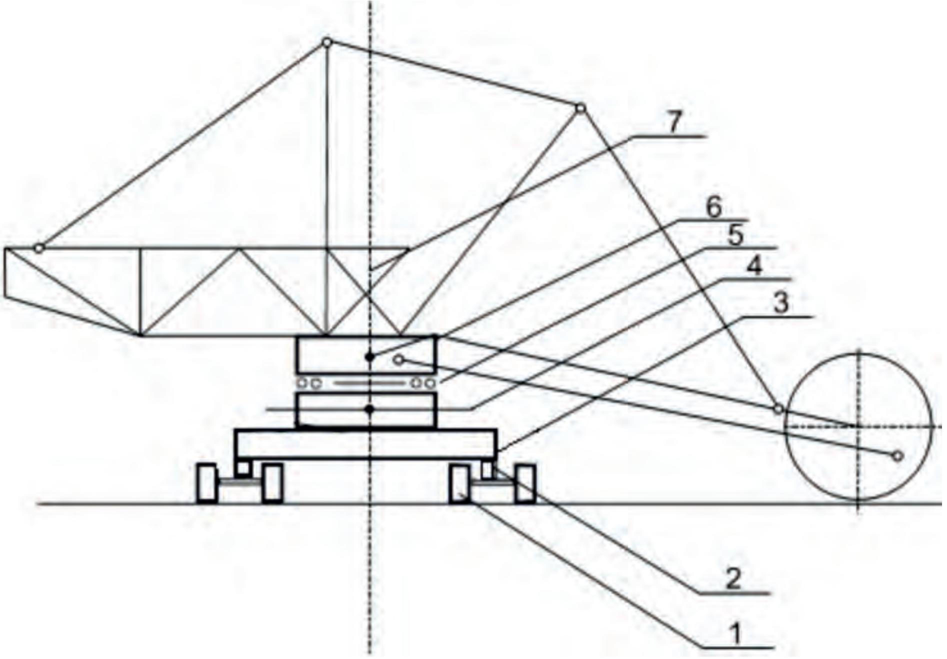

Fig. 3. Schematic diagram of the position of the chassis and superstructure bearing assemblies in the BWE
1- crawler travel mechanisms, 2 – crawler girder; 3 – chassis portal; 4 - lower annular girder; 5 – superstructure slewing assembly: ball or roller race; 6 - upper annular girder; 7 - machine superstructure.
Rys. 3. Schemat ideowy położenia zespołów nośnych podwozia i nadwozia w koparce wielonaczyniowej kołowej
1- gąsienicowe mechanizmy jazdy, 2- dźwigar gąsienicowy, 3- portal podwozia, 4- dźwigar pierścieniowy dolny, 5- zespół obrotu nadwozia: łoże kulowe lub rolkowe, 6- dźwigar pierścieniowy górny, 7- nadwozie maszyny

There are sockets installed in the side walls of the girder for mounting the journal connecting the traction assembly with the portal and the rocker arm axle holes of the crawler carriages (Fig. 4).

The ring-shape girder or body platform is the foundation of the entire superstructure assembly, i.e. tower, booms and masts. The chassis ring-shape girder with the portal is the foundation of the entire machine. It rests on the chassis portal and transfers to it the loads caused by all possible operating states of the entire machine. Also, the chassis portal loads, through the annular girder, the entire machine with various loads coming from the process of its movement, on the basis of feedback. There is no doubt that these structures – especially the chassis portal and its ring-shape girder – are primarily loaded with the total weight of the machine superstructure.

For the chassis portal, the weight of its ring is added to the total weight. In addition to static loads, there are also dynamic loads, induced by [1]:

- machine travel mechanisms (Fig. 5, Fig. 6) – in the event of failure of one of the chassis drives (which sometimes happens), the remaining drives, depending on the direction of travel, pull or push the damaged chassis, which significantly increases the lateral loads of the chassis portal structure and its ring-shape girder,
- start-up of the chassis, uneven travel and braking
- this usually causes fluctuations in the entire superstructure and additional reactions in the rolling components of the rotation mechanism,
- superstructure rotation – the centre of gravity of the machine does not usually coincide with the axis of rotation, and therefore, the distribution of loads in the ring-shape girder changes in the function of the angle of rotation,
- turning mechanism – in the case of a crawler chassis, certain minimum travel speed is required, at which you can start turning – otherwise the portal structure and crawler girders can be damaged,
- forces of inertia in the excavator system receiving bridge at a difference in the start-up or braking times of both machines or at individual displacements,
- the dynamics of the mining process – primarily affecting the structure of the superstructure ring-shape girder, but through the rotation assembly (ball races or trucks), also the entire machine chassis,
- excessive inclination of the superstructure due to loss of its stability, until the activation of the catch hooks.

Of the loads mentioned above, only the loads from the superstructure and the chassis deadweight are fixed, while the remaining load values change during the machine operation.

As you can see, the structure of the chassis carries a complicated set of loads. It must therefore be designed and calculated for extreme conditions. The time of correct operation should be equal to the machine lifetime. The only interchangeable – and as rare as possible – assembly should be the rolling assembly of the slewing mechanism, i.e. the ball races or a set of carriages and rail.

The properly balanced superstructure is an additional, very important factor [7]. Basic machines are subjected to modernization, reconstructions and overhauls during operation, as a result of which, the value and distribution of the deadweight and, consequently, the resultant position of the centre of gravity often changes. This condition may cause violation of the static balance conditions and consequently lead to serious failures including complete destruction of the machine.

Moreover, what is related to the above presented issue, if the centre of gravity of the superstructure deviates from the design position, accelerated wear of the slewing bearing raceways takes place, which, besides a decrease of its life, leads to additional loads of load-bearing structures, in particular the structure of girders. Failures of ring-shape girders are among the most frequent failures of load-bearing structures [1] and they cause frequent shutdowns of machines, which in turn affects the increase in operating costs.

The forces of interaction between the crawler and the ground are the most difficult to determine among all the loads acting on the chassis supporting structure. Values and time curves of forces derived from crawler assemblies can be determined in the case of existing facilities, experimentally or by using advanced numerical methods (also at the design stage)[8][9].

Sites selection method for monitoring the effort of chassis load-bearing structures

Due to particularly difficult working conditions and a relatively complex set of loads, the method of selecting sites to monitor the effort of chassis load-bearing structures has to be carried out in several stages in order to determine the best possible sites of maximum stress from both the static and dynamic loads described above. Because in the selection of monitoring sites, we usually deal with a machine subjected to many years of operation, the on-site visit in a real facility should be the first stage [2]. Its purpose is to identify any cracks and damages to structural components, measurements of deformations (including buckling elements), measurements of corrosion losses and checking the dimensions of structural components for compliance with specifications. At this stage, you should also collect all data on failures, modernizations, previous workflow, as well as check current operating parameters for compliance with the installation, operation and maintenance manuals.

The next stage of the method should be defining boundary conditions (for loads and cinematic constraints) to the calculation model of the chassis load-bearing structure. The use of the Dynamic Analysis and Design System (DADS) for multi-mass systems is very helpful for this purpose [10].

The DADS, by using the geometric and mass data entered as well as the characteristics of elastic and damping elements builds, using Lagrange equations of the second kind, a system of differential equations describing the motion of the object [11]. As a result of their numerical solution, we obtain time curves of position, velocity and acceleration of all components of the analysed object. The software also determines the values of forces and moments acting between the model components.

Fig. 4. Crawler girder (1) with drive gearbox (3) and motor (2) [18]
Rys. 4. Dźwigar gąsienicowy (1) wraz z przekładnią napędu jazdy (3) i silnikiem (2)

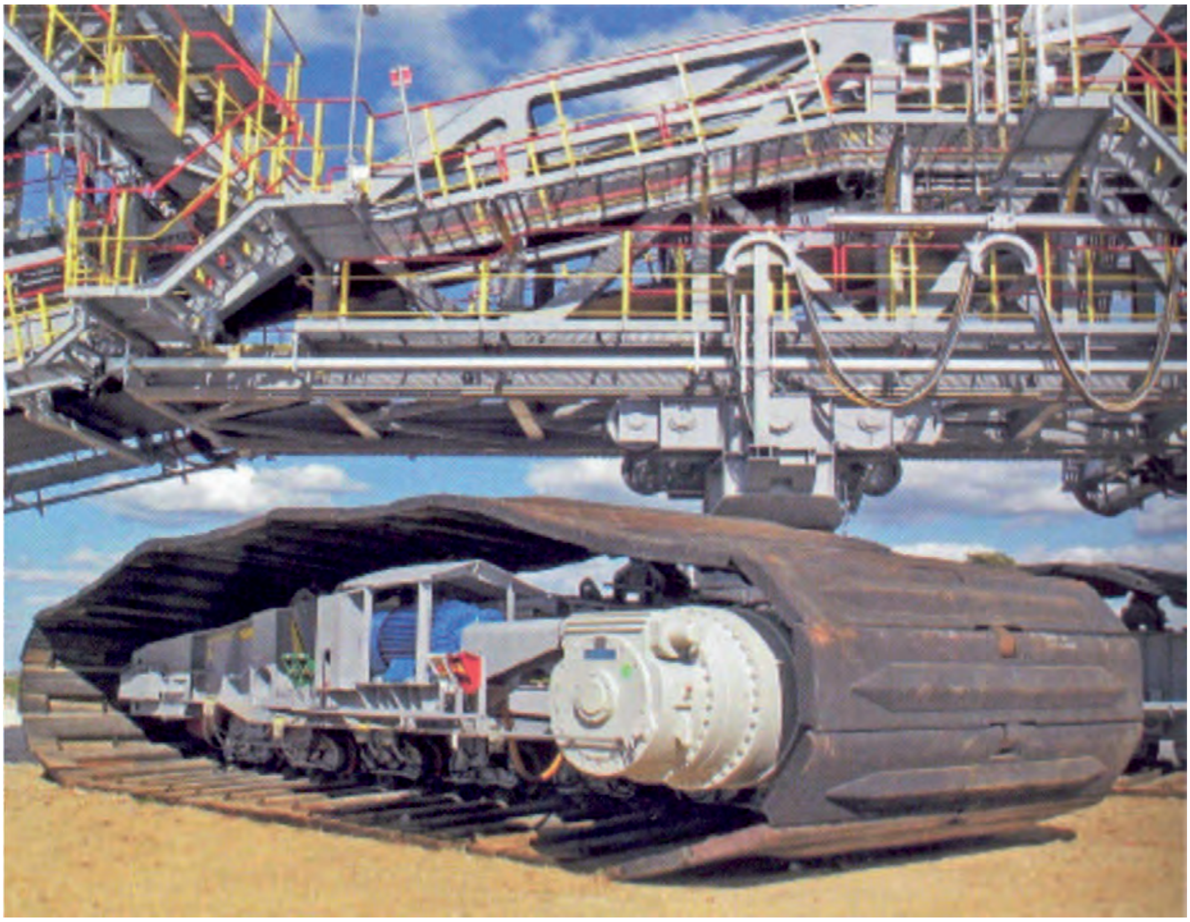

Fig. 5. The stacker driving mechanism
Rys. 5. Mechanizm jazdy zwałowarki

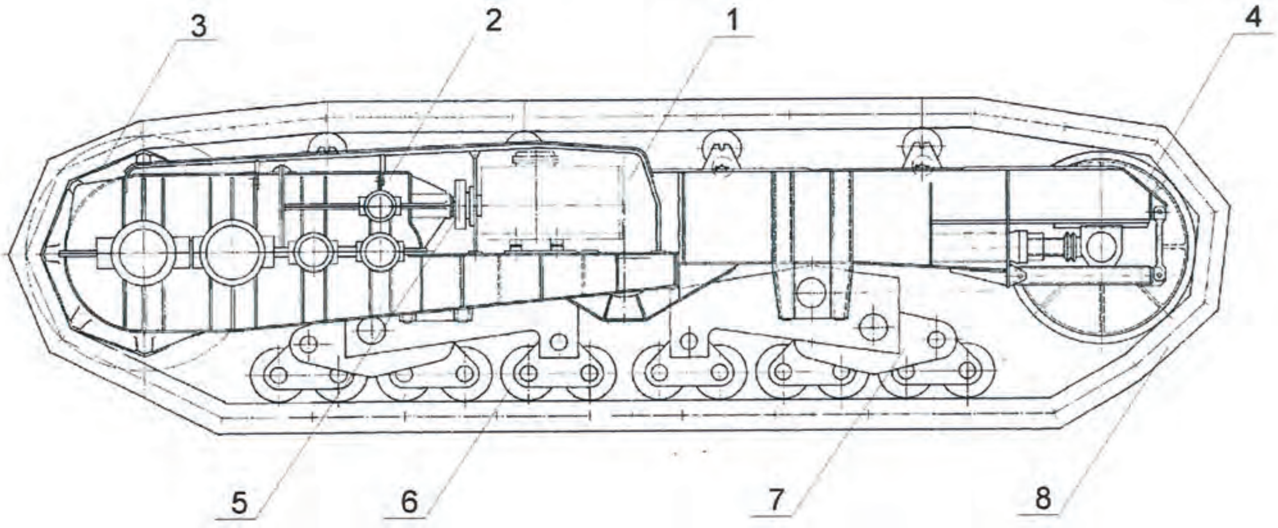

Fig. 6. Diagram of the BWE SRs 1200 driving mechanism
1- turning wheel, 2- bevel-cylindrical gearbox, 3- track sprocket, 4- turning wheel,
5- clutch assembly, 6- supporting wheel, 7- rocker, 8- crawler chain
Rys. 6. Schemat mechanizmu jazdy koparki SRs 1200
1- koło zwrotne, 2- przekładnia stożkowo-walcowa, 3- koło napędowe, 4- koło zwrotne,
5- zespół sprzęgieł, 6- koło wsporcze, 7- wahacz, 8- łańcuch gąsienicowy

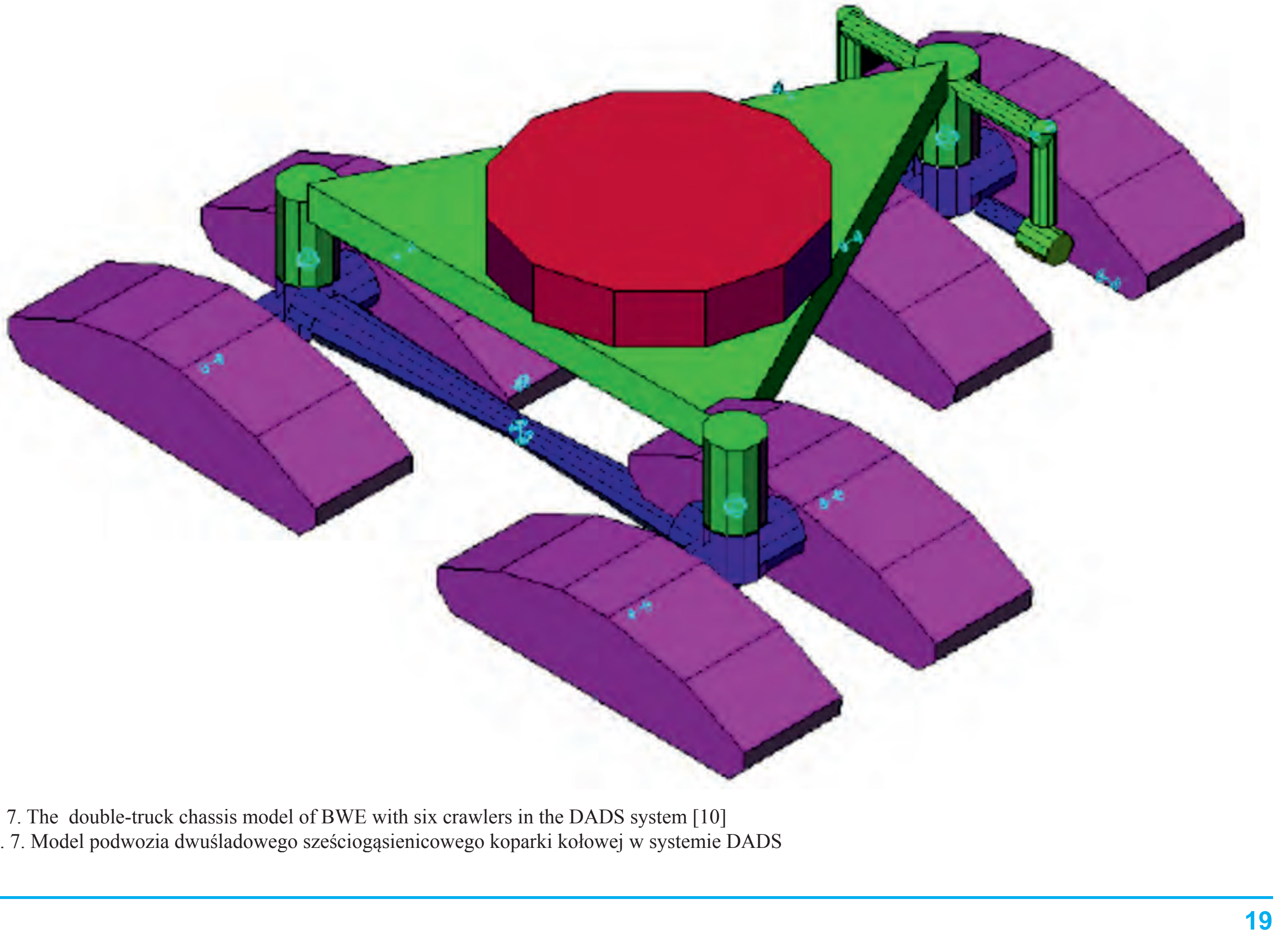

Fig. 7. The double-truck chassis model of BWE with six crawlers in the DADS system [10]
Rys. 7. Model podwozia dwuśladowego sześciogąsienicowego koparki kołowej w systemie DADS

The extension of the DADS software with an additional TRACK module increases its capabilities by allowing simulation of the crawler vehicle wheels and steering system. This module enables simulation of the operation of suspensions of individual wheels, including non-linear characteristics of elastic and damping elements. Each support wheel is attached to the body via the rocker arm and is provided with a spring and damping element of any characteristic. Between each rocker arm and vehicle body, it is possible to define a bumper with a given stiffness, limiting the maximum deflection.

The TRACK module considers the simulation of the crawler operation and its operation with the ground. The model built in this system also considers the ground deformability and tangential forces between the crawler and the ground.

The DADS enables comprehensive visualization of simulation results (Fig. 7). The results can be viewed both in the form of graphs and animations of the movement of the object.

The next stage of the method is the execution of FEM strength calculations. The calculations are carried out for load cases received as a result of using the DADS together with the TRACK module. FEM strength calculations are the most important factor in the above method, because they allow identification of the most loaded structural nodes of the chassis load-bearing structure. In the case of such complex assemblies as the load-bearing structures of the basic machine chassis, this task is very difficult and labour-intensive. Beam, beam-shell and shell models are commonly used in the FEM modelling [12]. The shell model is mostly used in modelling the chassis, due to its structure (extended plate girder elements), where each sheet (plate, shell) is modelled using a median surface, on which shell finite elements are generated with information on the sheet thicknesses. On the other hand, non-load-bearing assemblies, which load the chassis load-bearing structure, e.g. coming from drives, should be modelled using beam models. The above models allow for static and dynamic calculations of the chassis load-bearing structure. To evaluate the effort, substitute stresses are calculated, according to Huber-Mises for specific sets of loads (obtained e.g. as a result of the DADS simulation) and ranges of stress changes for fatigue strength evaluation. As a result of FEM calculations, sites are located on the load-bearing structure, where the values of maximum stresses occur (Fig. 8).

These areas are potential sites of durability loss resulting in damage, and are therefore locations, where stress sensors should be installed. For chassis load-bearing structure, the dynamics issues do not play such an important role as in the load-bearing structures of the superstructure, however, this assembly supports the superstructure, vibrations and oscillations of which are transmitted onto the chassis through the slewing bearing. For the chassis structural components, change of the loads resulting from the rotation of the superstructure, causing the centre of gravity to move, is the most important. Moreover, significant loads, including those of variable nature, occur during the failure (dragging) of one

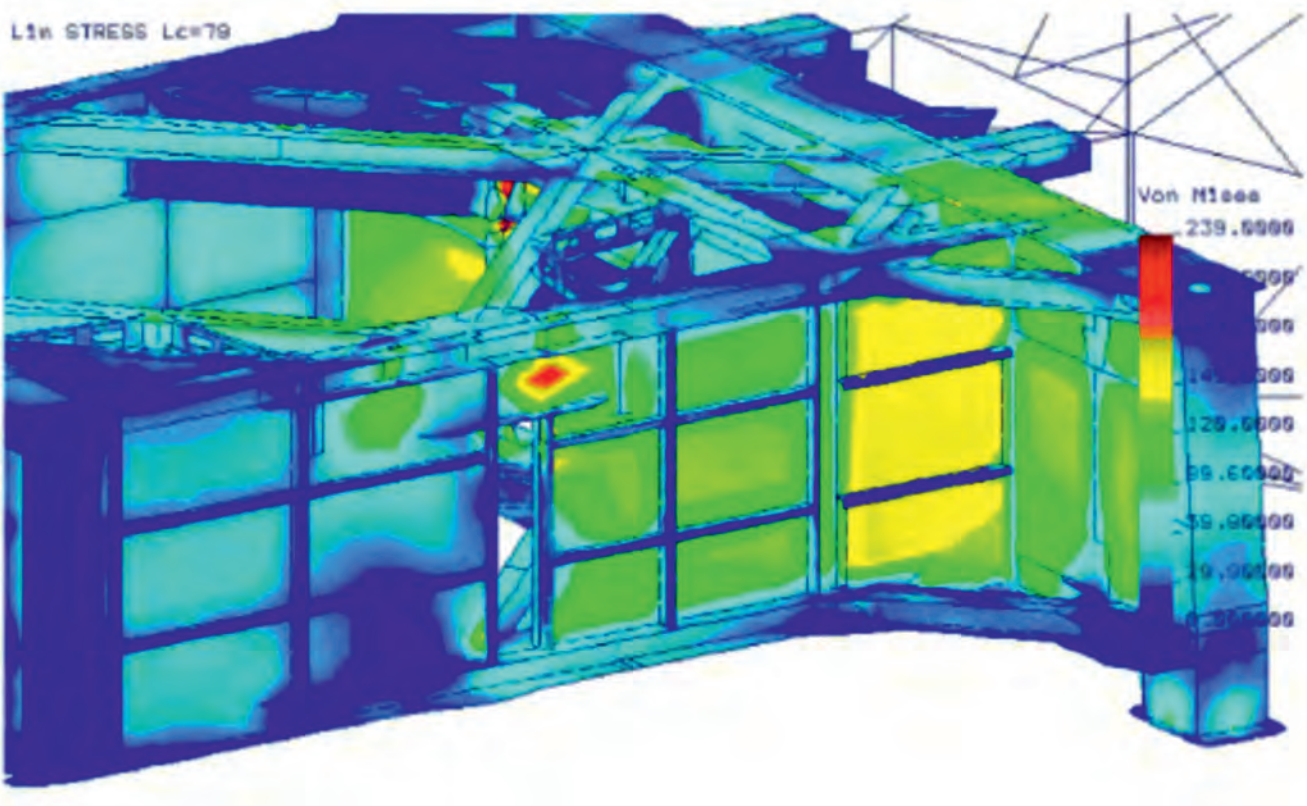

Fig. 8. Example of FEM calculations – contour of lines of reduced stresses in chassis structure of BWE SchRs 800 [17]
Rys. 8. Przykład obliczeń metodą MES - warstwice naprężeń zredukowanych w konstrukcji podwozia koparki SchRs 800

of the crawler vehicles and the twist of crawlers [11].

Due to the aforementioned complex set of loads, their considerable variability in time and the complicated chassis load-bearing structure, measurements of stresses from loads (both static and dynamic) should be carried out in order to verify calculation values, which is the next stage of the method. It should be limited to a maximum of a dozen or so measuring points, where maximum stresses have been found. The occurrence of maximum stress values implies, in turn, carrying out measurements for specific sets of loads (e.g. twist of crawlers or dragging of one of the crawler assemblies). Measurements should also be made in particularly endangered sites specified as a result of the first step of the above method (e.g. area of surface cracks). Measurements should be made using electric resistance wire strain gauges. Measurements of stresses from static loads should be made using the drill hole method [13].

The implementation of the above stages, which is a combination of numerical and experimental methods, guarantees the precise determination of measurement sites that can be used, among others. for the construction of systems for continuous monitoring the effort of the load-bearing structures in basic machines for opencast mining [14][15][16].

Summary and final conclusions

1. A description of the structure, work specifics and related loads of chassis load-bearing structures in basic machines for opencast mining has been presented in the paper. The total weight of the superstructure and, to a lesser extent, its deadweight are the dominant loads of the chassis load-bearing structures. These loads constitute approx. 80% of the total chassis load. Dynamic loads are the remaining ones.

2. Forces of interaction between the crawler and the ground are the most difficult to determine of all the loads acting on the chassis structure. Values and time curves of forces derived from crawler assemblies can be determined in the case of existing facilities experimentally or by using advanced numerical methods (also at design stage).

3. Based on previous studies it was found that global stress distributions did not pose any threat to the overall strength of the chassis load-bearing structure during its normal operation. However, there are particularly dangerous sites due to the stress accumulation caused by the notch effect, especially in the vicinity of welded joints. Significant concentration of stresses, and even exceeding their permissible level, can also occur during emergency situations, with a particularly dangerous case of damage to one of the crawler assemblies and dragging it through the remaining assemblies. Summing up, the previous research results are an important help in the selection of locations for monitoring of the chassis effort.

4. Sites selection method for monitoring the effort of chassis load-bearing structures in basic machines for opencast mining has been developed. The subsequent stages have been described in detail. The most important step here is to carry out strength calculations using the FEM, which allows identification of the most loaded structural nodes of the chassis.

5. The results presented in the paper enable a more rational selection of sites for monitoring the effort of chassis load-bearing structures in basic machines for opencast mining.

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